DETERMINATION AND ANALYSIS OF THE PRODUCTIVITY GAP

IN A

MEASURED DAYWORK SYSTEM

by

STEVEN R. HANNA

B.S., Kansas State University, 1973

A MASTER'S THESIS

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1979

Approved by:

Stephen K

Major Professor

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

A survey of work measurement and wage incentive systems (Rice, 1977) shows that 82 % of firms audited their work measurement systems. This percent applies only to the companies which participated in the survey. Most of the companies merely audit individual standards on a routine basis or audit performance reports. Of these companies, 5 % audited with work sampling techniques.

One example of a company using work sampling is the Hawthorne plant of Western Electric (Pitsch, 1976). Their procedure is to use a special form for work sampling called Work Occurrence Sampling (WOS) which allows the data to be summarized easily to detect loose standards, excessive operator idle time, and other nonproductive elements.

Krick (1962) outlines, in Appendix C of his book, several graphical techniques which can be used to determine loose standards or restricted output. In Figure 1 the dashed curve represents the distribution of the operators' outputs expected on the basis of their varied abilities. The solid curve indicates the distribution of the operators' outputs actually experienced when output is being restricted by the group.

Salvendy and McCabe (1976) determined that auditing of work standards can provide useful information regarding the accuracy of a plant performance report. Their study was an overall analysis. They stated some of the factors affecting the dependability of standards are:

1. Production variables; material variations, working conditions, supervisory effectiveness.
2. Dependability of fatigue and unavoidable delay allowances.

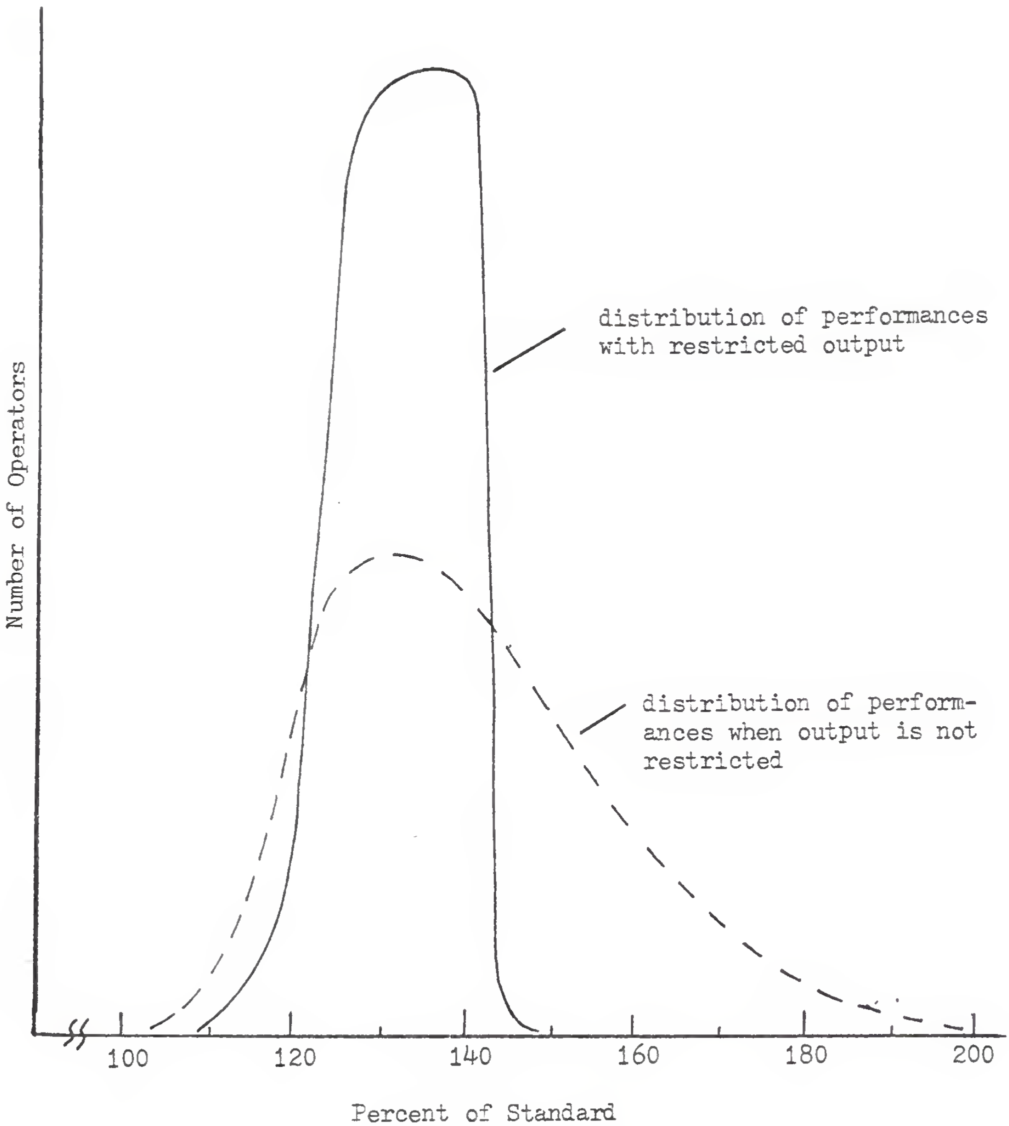

Figure 1. Graph of hypothetical performances when operators are restricting output (solid line) and when output is unrestricted (dotted line), Krick (1962)

3. Grouping effect for work standards based on predetermined motion time systems (PMTS); if a small number of elements constitute a standard, errors due to "round off" can occur.
4. Additivity of elemental times for standards based on PMTS. For certain tasks the times may be sub or supra-additive.
5. Transferability. Work standards are not uniformly applicable for all types of jobs with the same degree of accuracy.
6. Personnel determining the standard.
7. Operator performance during the time period when the work standard was determined.

Deere and Company has introduced a term "productivity gap" (unpublished report, Deere & Company, 1977) which they define as "...the percent difference between earned performance and the rated performance while working, plus the percent excess idle time taken by the employee." Calculation of the productivity gap utilizes random work sampling and comparing the results to the performance reports. Assumptions are made about the dependability of the reporting system, the representativeness of the work sample, the reliability of the personnel doing the work sampling, and rating of operator work pace.

PROBLEM

The purpose of this study is to: 1) create a set of operational definitions for terms such as productivity gap, operator work pace, operator personal time, fatigue, and miscellaneous delay, 2) take a work sample at Hesston Division to measure the various components of work done in the factory, 3) and analyze the data and compare it to the performance reports in order to obtain the productivity gap.

METHOD

Occurrence Sample

Because of an unavoidable time constraint, the occurrence sample was taken on Thursday, May 18, 1978 and Friday, May 19, for eight hours each day. Each day 480 samples were scheduled; actually 478 were taken on Thursday and 446 were taken on Friday. The four different departments were machining (01), fabrication (05), welding (39), and assembly (37). Five operators in each department were chosen by Hesston supervisors. The part numbers used were those routed to the particular work stations studied. Each eight hour shift (see Figure 2 and Figure 3) was divided into 32 blocks of 15 minutes time. The four departments were assigned to the time blocks according to two four by four Latin squares. Within each 15 minute block three samples were assigned randomly; the same five operators were observed in each sample. The physical route taken by the observer was altered between samples and between blocks by entering and leaving the three plants through different doorways as indicated in Figure 4. The observer rated the "productive work" elements. There were 513 of these in the 924 observations.

The shifts started at 7:00 A.M. and ended at 3:30 P.M. each day. The one half hour lunch at 11:30 A.M. was not observed. Two ten minute breaks are allowed each day from 9:00 A.M. to 9:10 A.M. and from 2:00 P.M. to 2:10 P.M. in assembly, welding, and fabrication, and from 8:50 A.M. to 9:00 A.M. and 1:50 P.M. to 2:00 P.M. in machining. These were sampled during the study because they are prorated into the industrial engineering standards.

A data sheet was used to record observations (Figure 5).

The time cards from each operator for each day were reproduced on an electrostatic copy machine so that comparisons between the work sample

Thursday--All Shops Combined

Fab 7:05 7:06 7:15	Mach 8:04 8:11 8:13	Weld 9:00 9:01 9:02	Assy 10:02 10:05 10:13	Mach 11:03 11:05 11:12	Fab 12:40 12:41 12:45	Assy 1:32 1:39 1:40	Weld 2:38 2:39 2:43
Mach 7:16 7:20 7:23	Weld 8:21 8:22 8:25	Assy 9:16 9:23 9:24	Fab 10:16 10:17 10:26	Weld 11:16 11:22 11:24	Mach 12:56 12:57 1:00	Fab 1:48 1:53 1:55	Assy 2:46 2:50 2:55
Assy 7:37 7:39 7:42	Fab 8:34 8:39 8:45	Mach 9:33 9:42 9:44	Weld 10:35 10:41 10:43	Fab 12:03 12:09 12:13	Assy 1:05 1:12 1:13	Weld 2:07 2:09 2:15	Mach 3:02 3:11 3:13
Weld 7:45 7:46 7:57	Assy 8:49 8:57 8:58	Fab 9:46 9:48 9:57	Mach 10:50 10:53 10:57	Assy 12:25 12:26 12:28	Weld 1:17 1:25 1:28	Mach 2:17 2:20 2:30	Fab 3:18 3:22 3:27

Figure 2. Two four by four Latin squares were used for assignment of conditions. The department sampled is indicated at the top of each block. Five operators were observed at each of the indicated times.

Friday--All Shops Combined

Weld 7:04 7:13 7:14	Assy 8:07 8:09 8.13	Fab 9:03 9:04 9:07	Mach 10:01 10:05 10:15	Assy 11:01 11:06 11:12	Weld 12:31 12:33 12:43	Mach 1:33 1:38 1:45	Fab 2:33 2:37 2:42
Assy 7:17 7:20 7:30	Fab 8:23 8:25 8:29	Mach 9:16 9:18 9:24	Weld 10:21 10:23 10:26	Fab 11:16 11:25 11:29	Assy 12:55 12:57 12:59	Weld 1:47 1:58 2:00	Mach 2:50 2:51 2:55
Mach 7:42 7:44 7:45	Weld 8:31 8:33 8:35	Assy 9:37 9:39 9:44	Fab 10:31 10:39 10:45	Weld 12:01 12:07 12:15	Mach 1:07 1:11 1:14	Fab 2:02 2:06 2:10	Assy 3:02 3:06 3:12
Fab 7:48 7:54 7:55	Mach 8:47 8:56 8:57	Weld 9:48 9:50 9:54	Assy 10:46 10:52 10:54	Mach 12:18 12:19 12:24	Fab 1:16 1:17 1:23	Assy 2:20 2:26 2:27	Weld 3:16 3:23 3:26

Figure 3. Two four by four Latin squares were used for assignment of conditions. The department sampled is indicated at the top of each block. Five operators were observed at each of the indicated times.

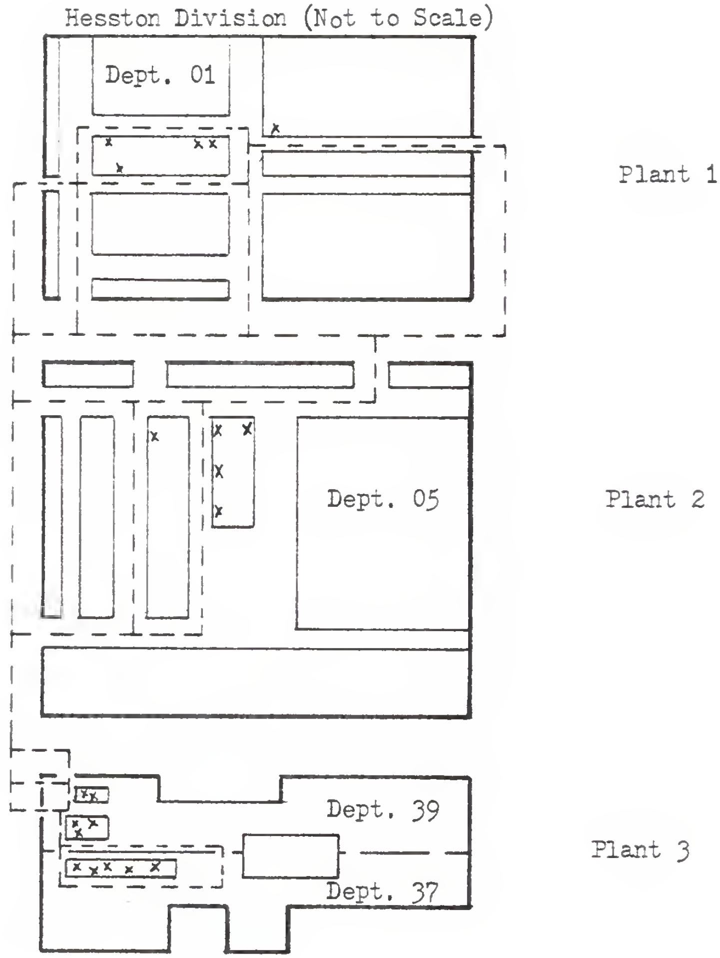

Figure 4. Plant layout showing the routes walked by the observer during the occurrence [illegible] Routes are indicated with a dotted line.

Dept.________ Observer____________ Shift__________ Date __________

Time	Operator	Machine Activity	Worker Activity	Effort Rating

Machine Activity:
1. Set up
2. Running
3. Idle
4. Down

Operator Activity:
1. Productive work on standard
2. Productive work on reason code
3. Reason code work on standard
4. Miscellaneous delay
5. Personal time
6. Operator not found
7. Enforced idle time
8. Daywork on reason code
9. Set up machine

Figure 5. Occurrence Sample Sheet

and the performance reports could be made.

The daily performance reports for each day for each operator were used to get the reported daily performance. The industrial engineering standard data sheet was obtained for each part number/operation number in order to compare the allowances in the work sample. The experimenter and two Hesston industrial engineers rated 20 Hesston film loops (provided by Rath and Strong, Incorporated) in order to validate the pace ratings. (The film loops were chosen by the Hesston industrial engineering manager.) The same two Hesston industrial engineers accompanied the experimenter during the occurrence sampling; they pace rated 45 sampling observations.

The following assumptions are necessary to calculate the productivity gap:

1. Personal allowances and fatigue allowances can be added together.
2. It is assumed that the operator used personal time evenly throughout the work day. If on daywork, he or she will not take personal and fatigue time which should have been taken during the measured daywork portion of the day.
3. Daywork (Reason code) time charges were allowed if a delay was sustained for ten minutes or more.
4. Delays less than ten minutes were classified as miscellaneous (job delays) and should be covered by allowances.
5. If the operator is completing daywork while performing against a standard (though this should never occur), the observations will be treated as miscellaneous delay.
6. Enforced idle time is accepted by the company as unavoidable and will be considered productive in regards to the operator.

7. Observations recorded as "operator not found" were computed as "personal time" observations.

Example of work sample summary for operator "Joe Smith" (non-machining):

Line	Description	Total Observations	Average(%)
a	Productive work on standard	70	
b	Productive work on reason code	0	
c	Reason code work on standard	2	
d	Miscellaneous delay	8	
e	Personal and fatigue	7	
f	Operator not found	3	
g	Enforced idle time	0	
h	Reason code work on reason code	10	
i	Set up machine	0	
j	Total observations	100	
k	Performance rating	--	120
l	Hours worked	16	
m	Personal and fatigue allowance		118

For the fabrication, welding, and assembly areas, productivity gap calculations are:

A. Average hours worked/(employee-day) = (l)/number of days worked = 16/2 = 8

B. Actual productive hours = A x ((a)+(b)+(g))/(j) = 8 x (70+0+0)/100 = 5.60

C. Normal hours on standard = B x (k)/100 = 5.60 x 120/100 = 6.72

D. Standard hours earned = C x (m)/100 = 6.72 x 118/100 = 7.93

E. Actual hours on standard = A x ((j)-((i)+(h)))/(j) =
8 x (100-(0+10))/100 = 720

F. % difference between observed miscellaneous delay plus reasons code work on standard and miscellaneous delay allowance (0.05 at Hesston) = (((c)+(d))/(a+b+c+d+e+f+g) - 0.05) x 100 = ((2+8)/(70+0+2+8+7+3+0) - 0.05) x 100 = 6.11

G. % earned performance = (D/E x 100) + F = 7.93/7.20 x 100 + 6.11 = 116.25

H. % productivity gap = G - (reported performance) = 116.25 - 100.00 = 16.25

I. % difference between allowed personal and fatigue allowance and observed personal and fatigue = (m)=(1.00+((e) +(f))/(a+b+c+d+e+f+g)) x 100 = 118-(1.00+(7+3)/(70+0+2+8+7+3+3+0)) x 100 = 6.89

Example of work sample summary for operator "Bill Jones" in machining:

Line	Description	Total Observations	Average (%)
a	Productive work on standard	55	
b	Productive work on reason code	0	
c	Reason code work on standard	2	
d	Miscellaneous delay	8	
e	Personal and fatigue	7	
f	Operator not found	3	
g	Enforced idle time	15	
h	Reason code work on reason code	10	
i	Set up machine	0	
j	Total observations	100	
k	Performance rating	--	120
l	Hours worked	16	
m	Personal and fatigue allowance	--	118
n	Machine running	38	

For the machine shop, productivity gap calculations are:

A. Average hours worked/(employee-day) = (l)/number of days worked = 16/2 = 8

B. Actual productive hours = productive work + enforced idle time = A x ((a)+(b)+(n)-.75((h)-(g)))/(j)=8x(55+0+38-.75(38-15))/100 = 6.06

C. Normal hours on standard = B x (k)/100 = 6.06 x 120/100 = 7.27

D. Standard hours earned = C x (m)/100 = 7.27 x 1.18/100 = 8.58

E. Actual hours on standard = A x ((j)-((i)+(h)))/(j) = 8 x (100-(0+10))/100 = 7.20

F. % difference between observed miscellaneous delay plus reason code work on standard and miscellaneous delay allowance (0.05 at Hesston) = (((c)+(d))/(a+b+c+d+e+f+g)-0.05) x 100 = ((2+8)/(55+0+2+8+7+3+15)-0.05) x 100 = 6.11

G. % earned performance = D/E x 100 + F = 8.58/7.20+6.11 = 125.29

H. % productivity gap = G-(reported performance) = 125.29-100 = 25.29

I. % difference between allowed personal and fatigue and observed personal and fatigue = (m)=(1.00+((e)+f))/(a+b+c+d+e+f+g)) x 100 = 118-(1.00+(7+3)/(70+0+2+8+7+3+0)) x 100 = 6.89

Data was summarized by operator, department and factory.

RESULTS

Productivity gap Figure 6 shows the distribution of pace ratings for the occurrence sample. The mean value was 101.5 % (σ = 8.1 %). A chi-square goodness of fit test was used to test for normality. Three tests were made using different intervals. For intervals with a width of 10 and ending in a 5 (for example, 86-95), the chi-square with two degrees of freedom was 18.8 while the table value (α = .05) was 6.0. For intervals 86-95.99, the chi-square with two degrees of freedom was 7.3. For intervals 81-85, 86-90 the chi-square was 18.8 as compared to the table value (α = .05, 7 degrees of freedom) of 14.1. Thus the pace distribution was not normal; it has a higher peak and less spread than a normal curve.

Figure 7 is the distribution of reported performances as taken from Hesston performance reports. The mean performance was 87.2 % (σ = 28.6 %).

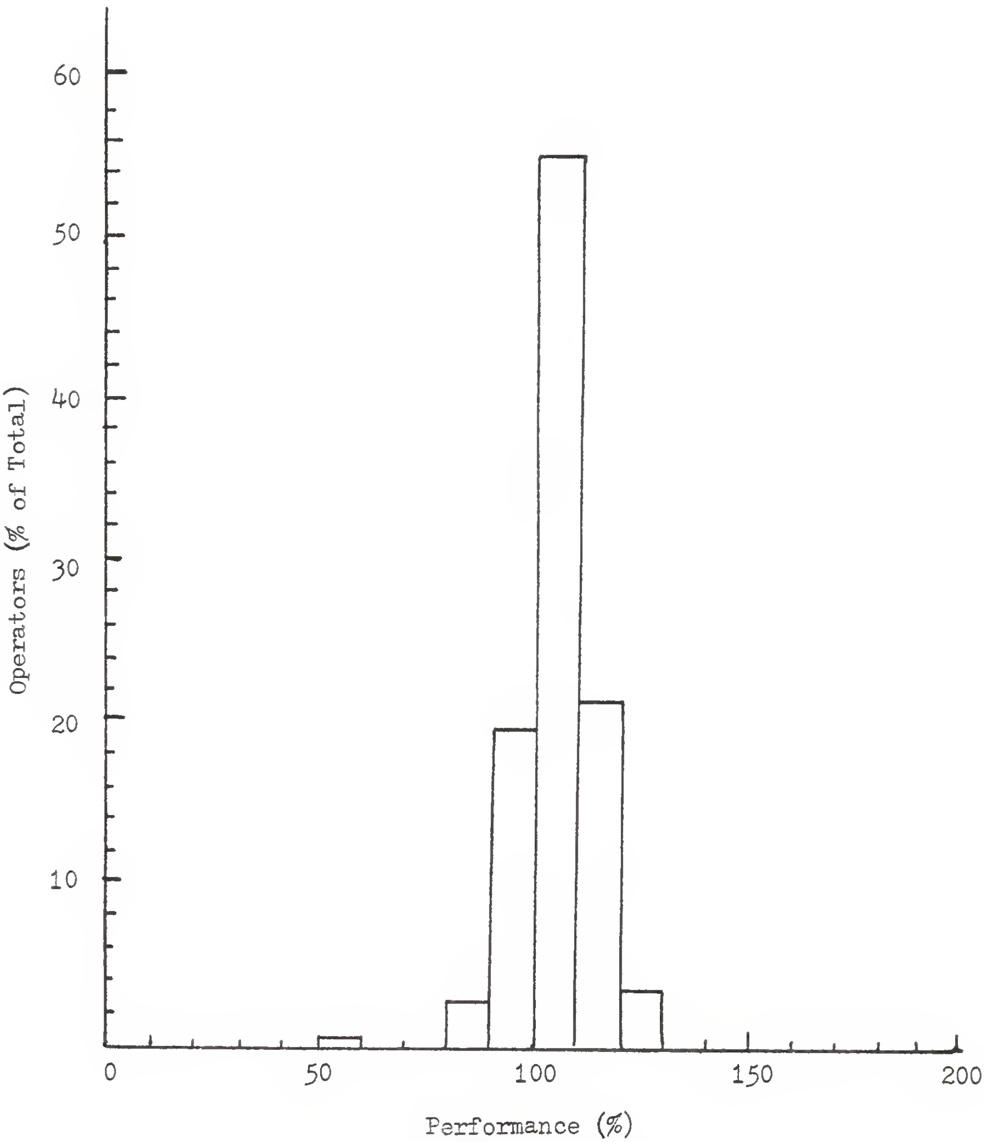

Figure 6. Distribution of Pace Ratings from the Occurrence Sample for all Departments Combined

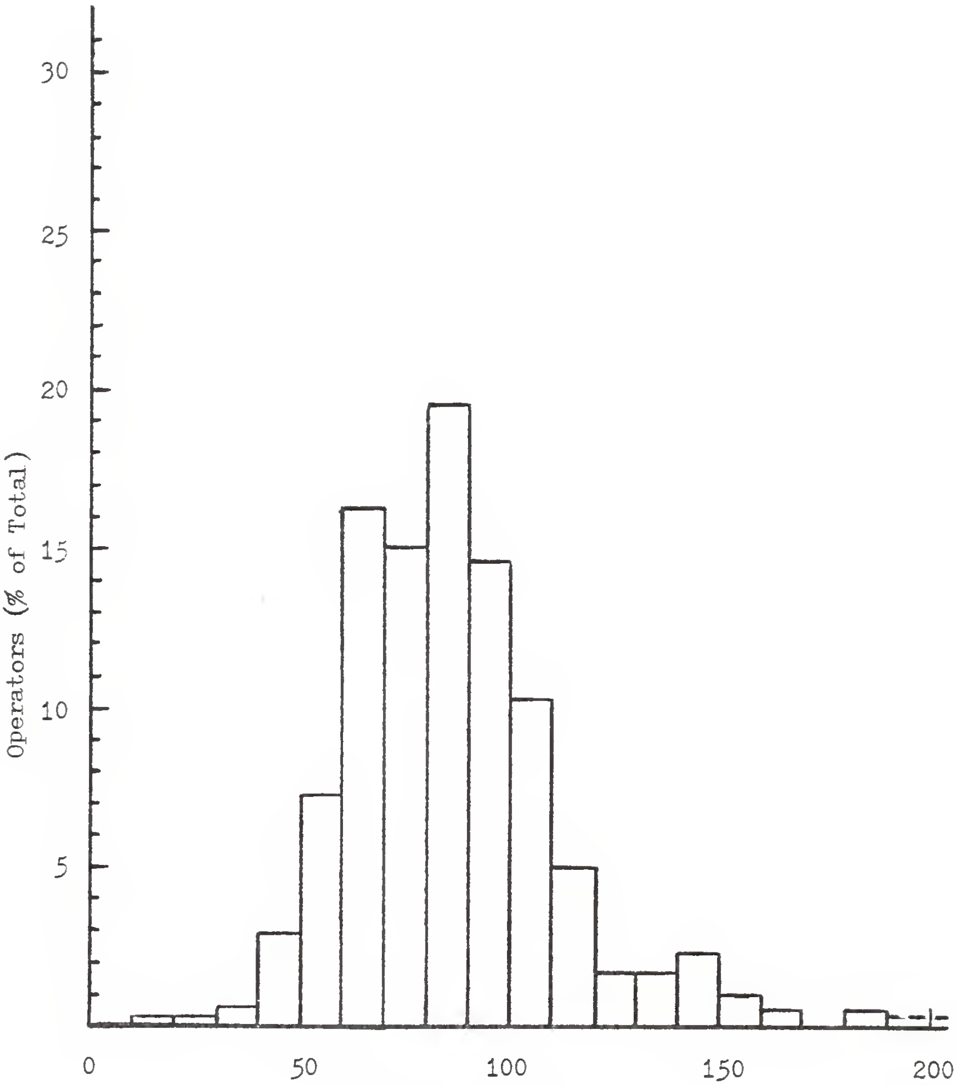

Figure 7. Distribution of Reported Performances from the Performance Reports for all Departments Combined

The wide variation in performances, especially those below 75 % and above 150 %, are probably the result of time card errors, misapplied standards, or creeping methods changes. By inspection, this distribution is comparable to Krick's (1962) curve for unrestricted output in Figure 1; the parameters of the Krick curve are not known.

Table 1 is the occurrence sample summary. Values are expressed as a percent of the 924 observations. The machine running column pertains to 225 observations on machine tools within machining and is separate from the 924 observations on the operators. The set up time in assembly is very low compared to the other departments. This low time is probably due to the limited sample size of this study. Miscellaneous delay, .8 % in welding, was well below the factory average. Machining had the largest value, at 7.1 %. Productive work was least in fabrication (33.3 %). This, combined with personal time of 32.9 %, agrees with the productivity gap for fabrication (Table 2) of - 44.6 %.

Figure 8 is a plot on normal probability paper of 26 normal random deviates against cumulative percent. For normally distributed samples the plot should be approximately linear, if the data is distributed normally. The plot was made to get an idea of the appearance of normal random observations so that a comparison could be made to Figure 9. Figure 9 is a plot of the 26 individual productivity gaps versus cumulative percent. By inspection, the productivity gap distribution appears to be normally distributed with a mean of -2.6 % (σ = 35.8 %). A sign test was performed on the individual productivity gap values. The calculated R = 11 (compared to critical R (.05, 26) = 7) was not significant.

TABLE 1 Occurrence Sample Summary

Dept.	Productive Work(%)	Miscellaneous Delay(%)	Personal Time (%)	Enforced Idle Time(%)	Day-work(%)	Set Up Time(%)	Machine Running (%)
Mach	36.4	7.1	5.3	9.8	16.0	25.3	44.9*
Fab	33.3	2.9	32.9	--	10.0	20.8	--
Assy	66.2	6.8	15.0	--	6.0	6.0	--
Weld	85.8	.8	12.0	--	---	1.3	--
Factory	55.2	4.4	16.5	2.4	8.0	13.4	--

* The machine running data given is for the 225 observations on the machine tools only and is not a part of the other percentages in the table.

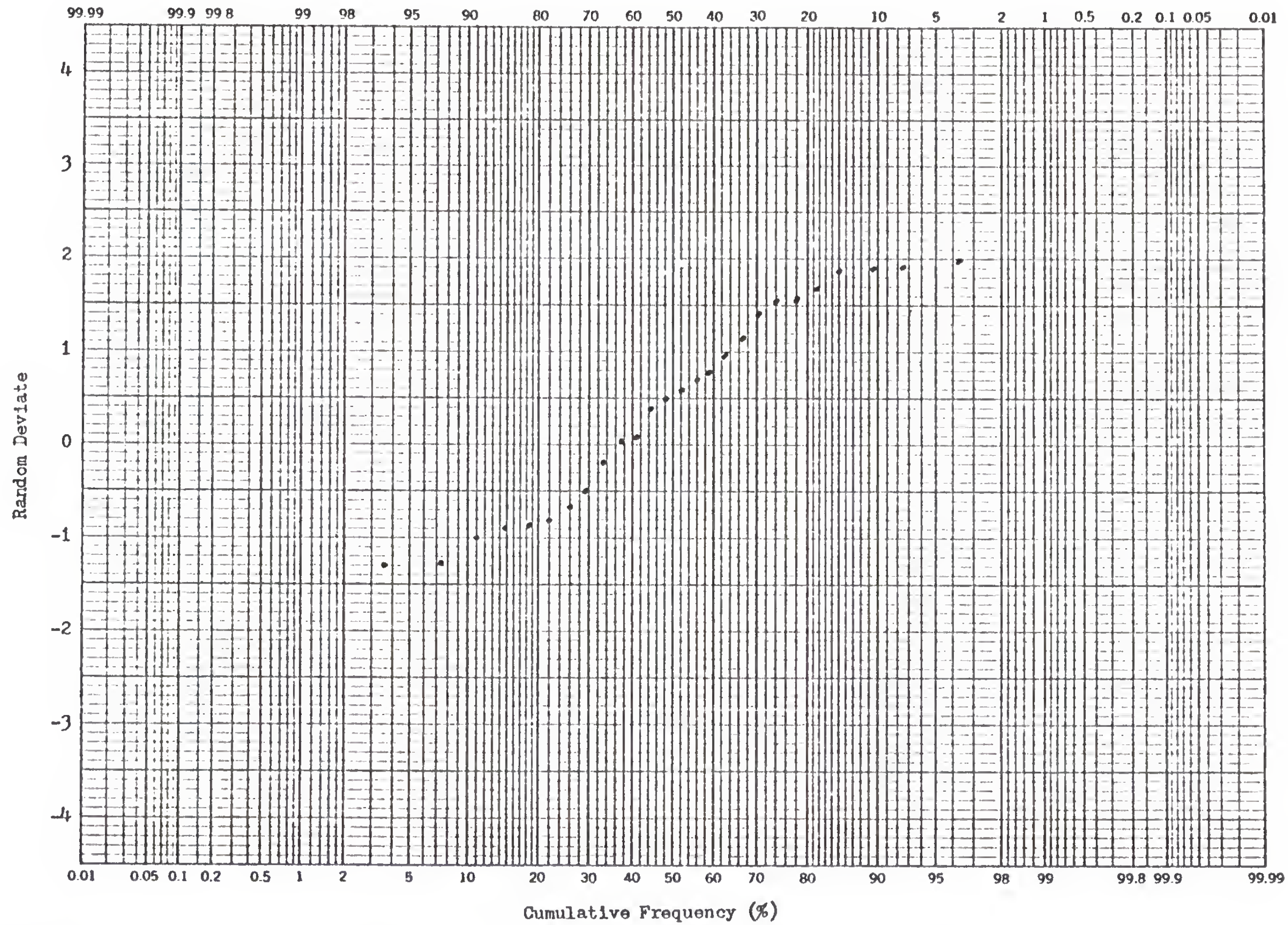

Figure 8 A Plot of 26 Normal Random Deviates on Normal Probability Paper

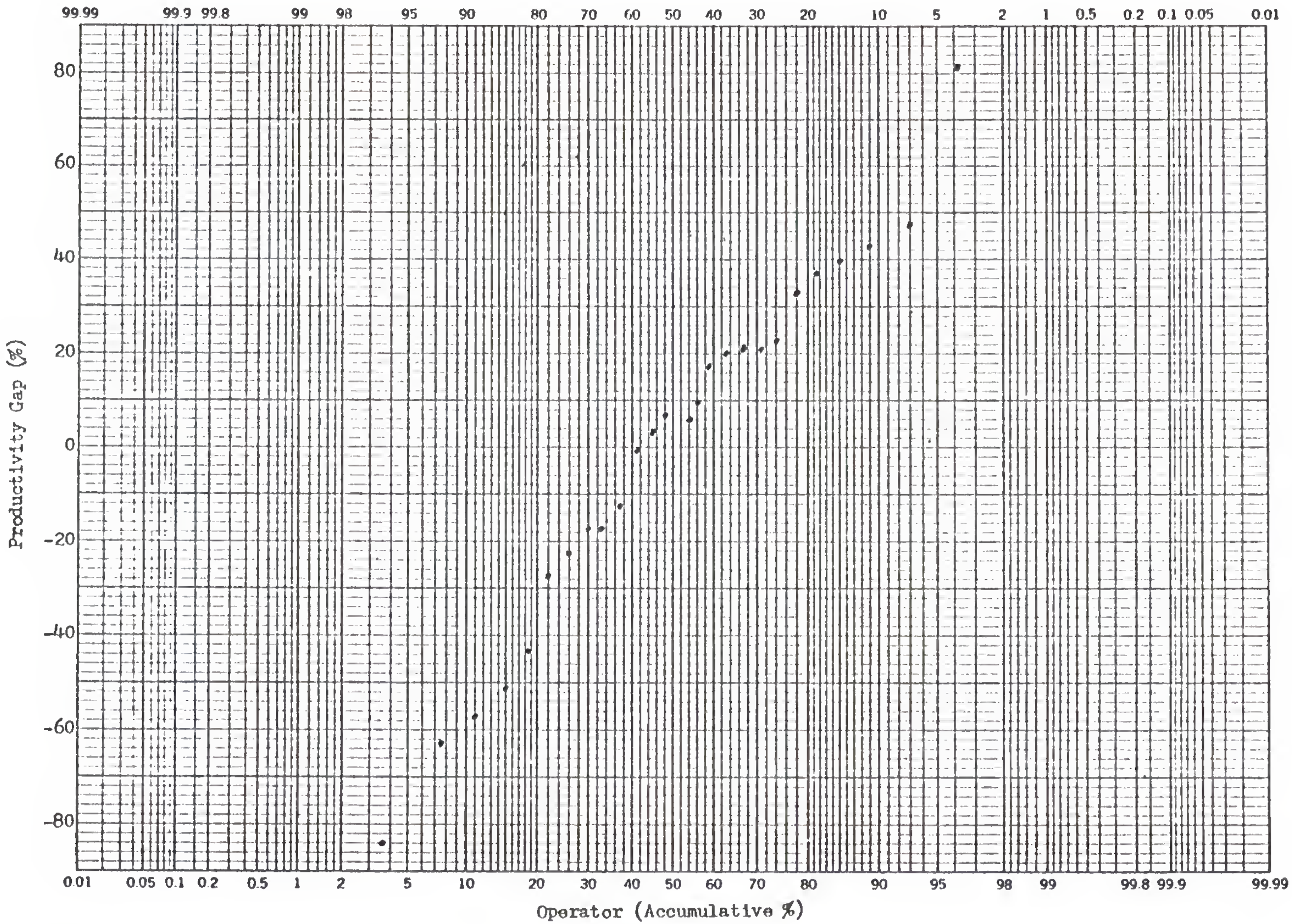

Figure 9 A Plot of 26 Productivity Gaps on Normal Probability Paper

In Table 2 the productivity gaps are summarized by departments. The largest productivity gap of - 44.6 was in fabrication . This corresponds to the previously reported results for fabrication in Table 1 (productive work of 33.3 % and personal and fatigue time of 32.9 %). This clearly indicates that operators in fabrication were overcompensated for their services. On the other hand, the productivity gap in welding compensates for this high value. Here the employees were undercompensated for work completed against standards. Although the work measurement system is "fair" on the average (as shown by the sign test) there is a large variation between departments. The departmental calculations do not numerically add to the factory average because they were weighted by the standard hours of contribution from each department.

Fatigue Table 3 shows the differences between allowed personal and fatigue time and the actual personal and fatigue time. Also included is the difference in actual job delay versus allowed job delay. Note that two departments had more than allowed delay and two had less than the allowed delay. Operator performance was not adjusted to reflect excessive job delay; however, it was adjusted to reflect the job difference if it was less than the allowance. That is, more output was expected for less job delay but the operator was not penalized for delays over 5 % (which would have been the same as placing the operator on daywork status).

A Student's t-test was performed on the data summarized in Table 4. The summary separates the pace ratings from the occurrence sample into morning and afternoon shifts. The mean rating was 104.1% for the first hour and 99.2 % for the 8th hour. The operators' mean work pace slowed significantly ($\alpha = .05$) from 102.3 % in the morning to 100.0 % in the afternoon, a difference of 2.3 %. This shows some additional fatigue occurred throughout the day.

TABLE 2 Summary of Productivity Gaps and Performances

Department	Earned Performance (%)	Paid Performance (%)	Productivity Gap (%)
Mach	113.4	116.7	- 3.3
Fab	55.1	99.7	-44.6
Assy	96.5	86.9	9.6
Weld	111.1	89.0	22.1
Factory Average	93.6	96.2	- 2.6

Negative productivity gap indicates company overpayment for services received from the employee.

TABLE 3 Difference Between Allowed and Actual Job Delay and Personal and Fatigue Times (P and F)

Department	Allowed Job Delay(%)	Actual Job Delay(%)	Allowed-Actual Job Delay(%)	Allowed P and F (%)	Actual P and F (%)	Allowed-Actual and F (%)
Mach	5.0	12.1	-7.1	14.0	9.0	5.0
Fab	5.0	2.9	2.1	15.0	47.5	-32.5
Assy	5.0	9.3	-4.3	18.0	22.7	- 4.7
Weld	5.0	.8	4.2	21.0	12.2	8.8
Factory Average	5.0	4.4	.6	18.0	21.0	-3.0

For job delay differences, a negative value indicates excess job delay as compared to allowed for job delay. For personal and fatigue differences, a negative value indicates the operator was resting or idle more than allowed for.

TABLE 4 Comparison of Operator Work Pace During the Morning and Afternoon, all Departments and Both Days Combined

Time	Number of Observations	Mean Pace Rating (%)	Standard Deviation (%)
7:00-7:59	70	104.1	8.0
8:00-8:59	75	103.1	9.1
9:00-9:59	66	101.2	6.9
10:00-10:59	61	100.6	8.6
11:00-11:30	33	102.3	8.5
7:00-11:30	305	102.3	8.3
12:00-12:29	16	94.1	4.9
12:30- 1:29	75	100.2	6.6
1:30-2:29	67	100.5	7.3
2:30-3:30	50	99.2	7.7
12:00-3:30	208	100.0	7.2

Rating calibration Time study analysts calibrate themselves by using rating films. Table 5 shows the comparison of pace ratings between the Hesston time study analysts and the observer taking the occurrence sample. The observer rated the same 25 observations that were available to the Hesston analysts. The two Hesston analysts are represented by 45 observations with a mean pace rating of 97.8 % (σ = 9.4 %). The mean pace rating by the observer was 105.2 % (σ = 25.5 %). Snedecor's F-test was used to test for different variances of the two samples. Since the calculated $F = 1.33$ was not significant ($\alpha = .05$), a Student's t-test was used to test for mean differences. The difference of 7.4 % between the observer's ratings and the analysts' ratings was significant ($\alpha = .05$).

Table 6 compares the Hesston analysts and the observer for the Rath and Strong rating (calibration) films. All rated the same film loops. The 20 loops were chosen by the Hesston industrial engineering manager. The same analysts that rated the observations summarized in Table 5 rated the Rath and Strong films.

The average for the calibration films was 127.3 %. The Hesston mean ratings were 122.5 % and 127.5 % which is within the plus or minus five percent criterion allowed to Hesston analysts. However, the 122.5 % and 127.5 % are significantly different. Relative to the calibration films, the observer, with an average rating of 116.8 %, is statistically and clearly "tight" by 10.5 % while the two analysts average 2.3 % tight.

DISCUSSION

Figure 6 represents a continuous distribution of operator work pace. It is the practice in industry to assume normality of this type of distribution. The distribution does not appear to be normal, as supported by

TABLE 5 Comparison of Pace Ratings by Hesston Time Study Analysts to Those of the Observer

Analyst	Number of Observations	Mean Pace Ratings (%)	Standard Deviation (%)
Observer (Author)	25	105.2	17.5
Hesston 1	25	94.0	6.1
Hesston 2	20	102.5	10.7
Hesston Total	45	97.8	9.4

TABLE 6 Film Rating Summary for Hesston Analysts and Observer

Analyst	Number of Observations	Mean Film Rating(%)	Standard Deviation(%)	Duncan's Multiple Range Test($\alpha < .05$)*
Rath and Strong Films	20	127.3	17.3	A
Hesston 1	20	122.5	15.3	B
Hesston 2	20	127.5	11.2	A
Observer	20	116.8	15.0	C

* Significance is indicated by different letters.

the chi-square tests. This sample has a much higher peak and less variance than a normal curve. It is known that the method of pace rating is subjective, and although the observer is trained to rate accurately to the nearest 5 %, it is difficult to rate operators working under 80 % and over 130 %. Because the performance ratings are to the nearest 5 %, changing the upper limits on the intervals rearranges large blocks of data, whereas if observers would rate to the nearest 1 % the interval would not have such a large effect.

Figure 7, the histogram of factory performances, graphically illustrates the theory by Krick (1962) as shown by the dotted line in Figure 1. The difference between the two plots is the shifted mean. In a measured daywork system with proper auditing procedures, accurately applied standards, and unrestricted output, the curve shape would be normal. The reason for the skewness is probably due to creeping methods changes, time reporting errors, and misapplied standards. It is hardly possible that an operator can work for sustained periods at 150 % performance. At Hesston Corporation the average allowances are 23 %. In order to obtain a daily performance of 150 %, an operator would have to maintain 185 % work pace throughout the day while facing the normal allowances.

Direct labor coverage is the ratio of time worked on standard to the total time worked by a direct hourly laborer. Direct hourly laborers, as defined by the Hesston accounting department, were sampled in this study. From the occurrence sample data (Table 1) the direct labor coverage is about 78.5 % (55.2 + 4.4 + 16.5 + 2.4). This is not a very high amount since it should be 92 % or greater. Machining had 25.3 % set up time which is unusual and would normally be less than fabrication which had

20.8 %. A more extensive occurrence sample should be completed before accepting these results on productivity gap.

How is fatigue reflected in performance? Possibilities are: 1) The operator will take personal and fatigue time in the form of rest periods evenly throughout the day. 2) The operator will not use the personal and fatigue allowance during the shift, but will work steadily and take rest when the work shift is completed. 3) The operator's work pace will gradually slow down as the day proceeds. Although no real information is available on the first two possibilities, Table 4 shows that some fatigue is reflected as a reduction in work pace verses time of day. The productivity gap calculations incorporate the daily average work pace, so this type of fatigue is accounted for. The operator is penalized for excessive personal and fatigue (P and F) time in the productivity gap equation (the company assumes they have allocated P and F correctly); and also, the operator is given credit for P and F not taken.

An important finding of the study is that the technique of combining occurrence sampling with performance rating permits estimation of the time effect of fatigue. Thus researchers have a tool with which they can measure fatigue.

Rating calibration seems to be a problem. Note that the Hesston analysts rated tighter than the calibration films by 2.3 % in the film rating session while the observer was 10.5 % tight. However they rated 7.4 % tighter than the observer when pace rating in the shops. See Tables 5 and 6. Thus they have changed their calibration when they leave the office and go into the shop. Using the observer's shop ratings as a base and adjusting his average rating by 10.5 % (according to the results in Table 6) to 115.7 % from 105.2 %, the Hesston analysts rate

17.9 % "tight". Thus, time study standards established at Hesston will result on the average, in a productivity gap which will undercompensate the employees for work performed against a standard.

This analyst change in calibration required a revised productivity gap calculation. The revised results are in Table 7. The factory average is now shown as 7.2 % (σ = 35.8 %) and the 68 % confidence interval is (.2 % $\leq$ gap $\leq$ 14.2 %). A sign test showed the adjusted plant-wide productivity gap results to be not significantly different from zero.

The variability between departments, even though the sample is small, indicates imbalance between departments in the manner in which the Hesston measured daywork system operates. The problem seems to be due to several sources. Further study is needed. Either the performances by the operators are unrestricted or the performances are being manipulated using improper data collection and reporting procedures. Examples of manipulation would be a supervisor allowing an operator to complete productive work during daywork time, or the time reporting system accepting inaccurate and incomplete time card information. These situations did not occur during the occurrence sample. Therefore, the conclusion must be made that the skewness of the reported performance is related to creeping methods changes, misapplied standards, and/or an inappropriate standard data base.

TABLE 7 Summary of Adjusted Productivity Gaps and Performances

Department	Earned Performance (%)	Paid Performance (%)	Productivity Gap (%)
Mach	125.0	116.7	8.3
Fab	59.1	99.7	-40.6
Assy	106.1	86.9	19.2
Weld	122.5	89.0	33.5
Factory Average	103.4	96.2	7.2

Negative productivity gap indicates company overpayment for services received from the employee.

Acknowledgements

Assistance was received in the areas of statistical analysis, summarizing data, and drawing conclusions from the data from Dr. D. L. Grosh.

Moral and financial support were received from D. L. Hanna.

REFERENCES

Krick, E.V. Methods Engineering. New York: Wiley, 1962.

Pitsch, R.E. Auditing Incentive Plans. Industrial Engineering. 1976, 8, 20-23.

Rice, R.S. Survey of Work Measurement and Wage Incentives. Industrial Engineering. 1977, 9, 18-31.

Salvendy, G. and McCabe, G.P. Auditing Standards by Sample. Industrial Engineering, 1976, 8, 25-29.

Appendix A: Alphabetical Listing of Operational Definitions

Enforced idle time--This is the amount of operator idle time paid for in the standard. Enforced idle time equals machine time minus 75% of the internal work time.

Fatigue allowance--This is a percentage factor applied to time study, MTM II, or General Purpose Data(GPD) elements to convert observed time into standard time. For example, assume the observed time to load a box weighing 35 pounds into a trailer from a storage pallet is ten seconds. Because the time study reading represents a short time of the operator's day and the operator will need to take rests or will slow down during the day, the observed time is multiplied by a fatigue factor of 1.20. The standard time is 10 x 1.20 = 12.0 seconds for this task (if only the fatigue allowance was applied).

Industrial engineering standard--Standards are the sum of individual time elements. Example: Assemble nut and bolt.

Element No.	Description of Task	Time(Hr /100 pieces)
1.	Pick up bolt, two feet from bench and position in hand.	0.097
2.	With combined motion, pick up nut two feet from bench and position to bolt.	0.023
3.	Turn nut and bolt with combined motion three turns.	0.046
4.	From hand held position, toss aside finished assembly to container.	0.023
	Standard	0.189

Allowances have been previously determined for data elements. The components for data are calculated as follows:

From hand held position, toss aside finished assembly (less than 2.5 pounds) to container (distance of move less than two feet).

	%	Hrs /100 pieces
Raw MTM II time		0.019
Personal time allowance	10	
Job delay allowance	5	
MTM II allowance	5	
Body position allowance	0	
Fatigue allowance	1	
Total allowances	21	x1.21
		0.023

Internal work--This is manual productive work which can be completed by the operator during the machine cycle.

Job delay, miscellaneous delay or unavoidable delay allowance--This is a percentage factor applied to MTM II, GPD or time study data to allow for delays which occur during the performance of work on standard. This allowance is for delays which are not cyclical in actual observation. The magnitude of the allowance was determined from a table; the table was obtained through extensive time study and/or from experience. (For an example, see the definition for industrial engineering standard.)

Performance rating, effort rating, or pace rating--This is a subjective estimate of operator skill and speed of movement while performing work. The base of 100% is defined, for hand type movements, as dealing 52 playing cards into four equally spaced stacks in 30 seconds. For

walking, 100% is a rate of three miles per hour on a straight and level surface carrying no weight. The ratings were made by a trained observer who has viewed and rated film loops of work tasks which have been developed by Rath and Strong, Incorporated, a well-known consulting firm.

Productivity gap--This is the percent difference between the earned and the paid performance plus the difference between actual miscellaneous delays plus reason code work on standard minus the allowed miscellaneous delay allowance.

Reason code or daywork--This is work performed which is not covered by a standard. This would be the same as clocking on and off standard or it could be a time allowance given to the operator at the end of the shift due to additional cyclical work done throughout the shift. An example would be deburring a part during the present operation which should have been deburred in the previous operation.

Standard data--These are tables of blocks of time composed of GPD, MTM II, or time study elements which are applicable to a specific process and/or work station design. An example would be "Get a part weighing between zero and 2.5 pounds from the floor, moving the part horizontally 4.5 feet, and positioning this part within zero to six inches in a waist high position in a fixture or on a work bench." The time would be 0.295 hours/100 pieces handled.

Time study--A record of observations on actual productive work. Observations consist of: a) elemental descriptions of the work done, b) the observed times for many cycles (as recorded by stopwatch or other time measuring equipment) of each of the elements, c) the operator performance rating, and d) the allowances for fatigue, personal delays, and unavoidable delay.

Example: Assemble nut and bolt.

Task	Average Raw Cycle Time, min	Performance Rating %	Normal Time	Total Allowance 1 + %/100	Standard Time Min/100
Pick up bolt two feet from bench and position in hand	.048	100	.048	1.21	.058
With combined motion, pick up nut two feet from bench and position to bolt	.013	95	.012	1.21	.014
Turn nut and bolt with combined motion three times	.024	95	.023	1.21	.028
From hand held position toss aside finished assembly to container	.011	110	.012	1.21	.014
Total standard time (Min/pc)					.114
Conversion factor to obtain (Hr /100)					x 1.667
Standard (Hr /100 pieces)					.190

Appendix B   Data for Pace Ratings in Occurance Sample

Interval Upper Limit (%)	Pace Ratings (Number of Operators)
55	1
60	
65	
70	
75	
80	8
85	4
90	49
95	47
100	205
105	56
110	83
115	21
120	13
125	2
Mean	101.5 %
Standard Deviation	8.1 %

Appendix C Data for Reported Factory Performance

Upper Limit (%)	Department: 01	05	37	39	Total
	Number of Operators				
20				1	1
30				1	1
40			1	1	2
50	1	3		9	13
60	7	8	3	14	32
70	11	19	15	27	72
80	9	24	12	22	67
90	18	23	23	23	87
100	16	11	31	6	64
110	12	14	10	10	46
120	10	4	5	3	22
130	2	2	1	2	7
140	1	2	3	1	7
150	2	4	2	2	10
160		1	1	2	4
170		1		1	2
180					
190				2	2
200 or More	1	3			4
Totals	90	119	107	127	443

Appendix D Data for Productivity Gap Calculations

Operator	Average Hrs. Worked/Day	Av. Pace Rating(%)	Av. Allowance Factor	Earned Performance (%)	Reported Performance (%)
101	8	100.9	1.22	116.8	107.3
201	8	95.4	1.19	83.2	105.7
301	8	98.5	1.18	149.8	110.1
401	8	100.8	1.20	141.2	184.9
501	8	94.5	1.19	94.4	91.2
601	8	98.6	1.23	110.8	89.3
105	8	89.0	1.37	33.0	116.6
205	8	97.5	1.24	81.0	63.3
305	8	97.5	1.16	56.6	119.6
405	8	96.5	1.18	77.6	71.7
505	8	87.6	1.16	70.3	87.1
605	8	94.3	1.16	70.6	91.7
705	8	95.0	1.16	67.8	125.6
137	8	104.5	1.16	83.3	110.3
237	8	98.7	1.21	97.9	93.2
337	8	99.4	1.26	100.8	113.5
437	8	99.3	1.20	83.3	63.7
537	6.88	97.5	1.28	102.3	59.6
637	8	98.7	1.19	100.7	78.6
737	8	105.0	1.20	110.3	111.7
139	8	105.1	1.20	106.1	83.5
239	8	107.0	1.28	149.7	102.8
339	8	105.7	1.29	109.8	72.9
439	8	105.7	1.28	99.5	117.0
539	8	104.5	1.25	119.7	87.0
639	8	102.6	1.29	132.4	50.8

Appendix E Occurrence Sample Summary by Operator

Operator	Productive Work	Miscellaneous Delay	Personal	Daywork and Set Up	Enforced Idle Time	Machine Running
101	14	3	0	18	10	15
201	12	2	5	24	2	8
301	16	2	0	24	3	32
401	19	1	0	24	1	21
501	10	4	4	3	3	11
601	11	4	3	0	3	14
105	10	3	27	8		
205	4	0	2	18		
305	22	1	19	6		
405	10	1	4	9		
505	18	0	11	18		
605	7	1	11	6		
705	9	1	5	9		
137	11	0	5	8		
237	19	2	3	0		
337	39	3	7	0		
437	30	4	11	3		
537	22	2	6	11		
637	19	2	2	1		
737	15	3	1	5		
139	37	0	7	0		
239	41	0	1	3		
339	38	1	7	0		
439	34	1	10	0		
539	22	0	2	0		
639	21	0	0	0		

DETERMINATION AND ANALYSIS OF THE PRODUCTIVITY GAP IN A MEASURED DAYWORK SYSTEM

by

STEVEN R. HANNA

B.S., Kansas State University, 1973

AN ABSTRACT OF A MASTER'S THESIS

Submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1979

Abstract

The productivity gap was determined at Hesston Corp. by analysis of an occurrence sample combined with performance rating. The two day sampling plan of 924 observations covered four departments and 26 operators. The components of work analyzed were productive work, daywork, miscellaneous delay, enforced idle time, personal and fatigue time.

Equations were developed to compare the sample results to the Hesston allowances for miscellaneous delay, personal and fatigue time and productive work. Productivity gap was defined and an equation was constructed to reflect the overall performance of Hesston's work measurement program.

While the average productivity gap is not significantly different from zero, there is considerable undercompensation to employees in welding for work performed and considerable overcompensation to employees in fabrication for work performed. This indicates some inconsistency in standards application and maintenance of the work measurement program.

Fatigue, indicated by a decrease in rated performance, increased during the day. The mean rating was 104.1% for the first hour and 99.2% for the 8th hour; the mean for the first four hours was 102.4% and the second four hours was 100.0%. Thus it appears that the technique of combined performance rating and occurrence sampling can be used to measure the effects of fatigue.

The Hesston analysts were not consistent between the rating films and job observations; they rated 8.3% higher than the author on the films and 7.4% lower for the jobs. Thus they changed their "calibration".